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Cost and Performance Report

(MM-0037)

Enhancement and Utilization of Airborne Magnetometry for the Detection, Characterization, and Identification of Unexploded Ordance (UXO)

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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AGL	above ground level
ADU	Attitude determination unit
AF	airfield
ALASA	as low as safely allowable
APG	Aberdeen Proving Ground
ARF	active recovery field
BBR	Badlands Bombing Range
BRAC	base realignment and closure
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CTT	Closed, Transferred, and Transferring
DAS	data analysis system
DER	designated engineering representative
DGPS	differential global positioning system
DoD	Department of Defense
DOE	Department of Energy
DP	dewatering ponds
EE/CA	engineering evaluation/cost assessment
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FAA	Federal Aviation Administration
FOM	figure of merit
FUDS	formerly used defense site
GPS	global positioning system
ha	hectares
HM3™	Helicopter-Mounted Magnetometer Mapping
IDA	Institute for Defense Analyses
ISMS	Integrated Safety Management System
MGD	mine, grenade, and direct-fire
MTADS	Multisensor Towed Array Detection System
NAD	North American Datum
NRL	Naval Research Laboratory

ACRONYMS AND ABBREVIATIONS (continued)

nT	nanotesla
ORAGS	Oak Ridge Airborne Geophysical System
ORNL	Oak Ridge National Laboratory
P_d	probability of detection
QA	quality assurance
QC	quality control
RT-DGPS	real-time differential global positioning system
STC	Supplementary Type Certificate
Stdev	standard deviation
USAESCH	U.S. Army Engineering and Support Center, Huntsville
UTM	Universal Transverse Mercator
UXO	unexploded ordnance

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Enhancement and Utilization of Airborne Magnetometry for the Detection, Characterization, and Identification of Unexploded Ordnance (ORAGS-Arrowhead Total Magnetic Field System), which documents the development, design, construction, acquisition, processing, analysis, and interpretation of airborne remote sensing data for unexploded ordnance-related sites, was prepared by the Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL) and the U.S. Army Corps of Engineers Engineering & Support Center, Huntsville (USAESCH) under Military Interdepartmental Purchase Requests (MIPR) W31RYO90696 and W31RYO91270. This work was prepared through funding provided by the Environmental Security Technology Certification Program Office (ESTCP). This project offered the opportunity to examine advanced airborne methods for applicability at Department of Defense (DoD) sites that contain unexploded ordnance and ordnance-related artifacts, such as waste burial sites, that present environmental health concerns as well as safety concerns for personnel.

We wish to express our sincere appreciation to Dr. Jeffrey Marqusee, Dr. Anne Andrews, and Mr. Jeffrey Fairbanks of the ESTCP Office for providing support and funding for this project.

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1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

As a result of past military training and weapons-testing activities, an estimated 6 million hectares (ha) (approximately 15 million acres) of U.S. land is potentially contaminated with unexploded ordnance (UXO) and/or weapons testing- and training-related artifacts. These contaminated areas include sites designated for base realignment and closure (BRAC) and Formerly Used Defense Sites (FUDS). Using current technologies, the costs associated with detection, identification, and mapping of this contamination has been estimated to be in the tens of billions of dollars. Current surface-based technologies are generally labor intensive, slow, and expensive. Significant cost savings could be achieved if it is demonstrated that advanced airborne methods can provide a substitute for a portion of the surface-based applications. Typically, airborne magnetometers have not been used for UXO detection due to limitations in the physics and an inability to position the magnetic sensors in close proximity to the targets at or beneath the earth's surface. Recent demonstrations and advances in airborne magnetic systems have led to significantly improved performance over prior generation airborne systems. Although airborne systems do not match the resolution and sensitivity of ground-based surveys, an airborne approach provides the option for personnel to conduct surveys without contacting potentially explosive devices, and offers a relatively nonintrusive approach by reducing the disturbance of indigenous plant and animal habitat that often accompanies ground geophysical activities (i.e., brush cutting).

The fourth-generation airborne system developed and utilized for ESTCP projects 200037 and 37 was based on eight airborne-quality cesium vapor magnetometers mounted in three rigid 6 m booms (one forward, two lateral) that are mounted to the airframe of a commercial helicopter. Ancillary equipment included a laser altimeter and a real-time differentially corrected global positioning system (GPS) for navigation and data positioning. This configuration enabled operation at a nominal flight altitude of 1 to 3 m above ground level (AGL). The survey methodology consisted of parallel lines traversing the areas of interest with the survey lines adjacent to one another (as opposed to being interleaved as with the second-generation system) so that eight traces of total magnetic field data were collected for each flight line, providing a nominal data spacing of 1.75 m with a flight line spacing of 12 m. The survey process concludes with data processing, analysis, interpretation, and mapping using commercial software to generate digital images depicting locations and magnitudes of anomalies that may represent UXO.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of these projects was to evaluate an improved airborne high-resolution magnetic system for the detection and mapping of probable UXO-related contamination. This objective was to be accomplished by validating detection and characterization of ordnance and ordnance-related debris at large previously unsurveyed areas and at controlled test sites using airborne magnetometer technology. These demonstration surveys produced results confirming that this improved technology is both practical and cost-effective for detection and mapping of certain categories of UXO as well as wide-area surveillance associated with footprint reduction activities.

1.3 REGULATORY DRIVERS

No specific regulatory drivers influenced this technology demonstration. UXO-related activity is generally conducted under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) authority. A draft Environmental Protection Agency (EPA) policy related to UXO is currently under review. Regardless of a lack of specific regulatory drivers, many DoD sites and installations are aggressively pursuing innovative technologies to address a variety of issues associated with ordnance and ordnance-related artifacts (e.g., burial sites) that resulted from weapons testing and/or training activities. These issues include footprint reduction and site characterization, areas of particular focus for this technology demonstration. In many cases, the prevailing concerns at these sites can lead to airborne surveying and other remediation activities despite the absence of relevant regulatory drivers and mandates.

1.4 DEMONSTRATION RESULTS

To validate the detection capabilities of the system, several controlled test sites (Calibration Sites) developed under previous ESTCP-funded projects or other DoD-funding projects were surveyed in addition to surveys conducted on actual UXO-contaminated sites (e.g., Aberdeen Proving Ground [APG], Badlands Bombing Range, Sierra Army Deport, Nomans Land Island). Seeded items included engineering items, inert ordnance, and simulants that were selected to bracket the expected detection parameters of the system. Actual ordnance items at the survey sites included all manner of ordnance ranging from 60-mm mortar rounds up to 1,000-lb general purpose air-deployed bombs. Detection rates varied with the size of the targets and site conditions. Results show that the system typically achieves detection rates of better than 70% (and sometimes 100%) for larger ordnance, while rates of 30-70% are more typical for 60 mm, 81 mm, and smaller items. The rate of coverage for the surveys ranged between about 40 and 140 acres/hr (16-57 ha/hr) and the average survey speed was about 20 m/s, except where the survey area was too small for efficient operation. The average distance between the actual locations of the excavated items and the predicted locations from helicopter anomalies was consistently less than 1 m. Noise levels were typically 1-3 nanotesla (nT) in the raw data and less than 0.1 nT in the filtered data.

1.5 STAKEHOLDER/END-USER ISSUES

Issues related to these demonstration projects center on the appropriate use of the technology. Clearly, the improved airborne system is unable to detect all UXO items of potential interest. The technology continues to be constrained by the presence of tall vegetation and rough terrain that increases the distance between the system and the UXO items of interest, thereby limiting detection ability. It remains apparent that application of the technology to small survey areas will not be cost-effective due to the large cost associated with mobilization/demobilization and considerable helicopter costs. Users should consider both the intended UXO targets and survey area (size, terrain, and vegetation) before considering the use of airborne systems for UXO detection, mapping, and/or footprint reduction.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

Many methods have been proposed for the detection and identification of UXO. Surface and airborne measurements of the perturbations in the direction and/or strength of the earth's magnetic field can be used to locate underground ferromagnetic objects and structures. Although these methods have typically been used to characterize geologic features, they are also effective in locating ferrous man-made objects. Surface-deployed instrumentation offers greater sensitivity at significantly higher acquisition costs (ranging from as low as $500 to more than $3,000 per acre, depending on survey instrument type and site conditions). They are extremely time-consuming and may present risks to personnel, equipment, and the environment.

With an estimated 6 million ha (approximately 15 million acres) of U.S. land potentially contaminated with UXO and/or weapons testing-related artifacts, the costs associated with the detection, identification, and appropriate cleanup of this contamination could be tens of billions of dollars. Significant cost savings could be achieved if airborne methods can serve as a substitute for a portion of ground-based methods. Airborne magnetometers have not been used for UXO detection due to limitations in the physics and an inability to position the magnetic sensors in close proximity to the ground. Recent advances in airborne magnetic systems have demonstrated capabilities that approach those of surface-based systems.

In the Oak Ridge Airborne Geophysics System (ORAGS) -Arrowhead system used by this project (see Figures 1 and 2), cesium vapor magnetometers are mounted at regularly spaced intervals in three rigid booms (one forward arrowhead-shaped 6 m boom, two lateral straight 6 m booms) mounted on the underside of the aircraft. This total field system is considered a fourth-generation airborne magnetometer array in the ORNL development timeline. Changes from the previous ORNL airborne magnetometer array, the ORAGS-Hammerhead, include a new boom architecture designed to position sensors at new lower-noise locations and a new aircraft orientation (attitude measurement) system. The new attitude measurement system is based on four GPS antennas rather than a fluxgate magnetometer measurement used in previous generation systems. For the ORAGS-Arrowhead system, four magnetometers at 1.7 m spacing are located in a forward V-shaped boom, and two magnetometers with equivalent spacing are located in each of the lateral booms. Although the spacing is similar to that of the predecessor ORAGS-Hammerhead system, the forward positioning of two magnetometers that were previously the innermost rear boom magnetometers on the ORAGS-Hammerhead system improve noise conditions in the ORAGS-Arrowhead over those of the ORAGS-Hammerhead system.

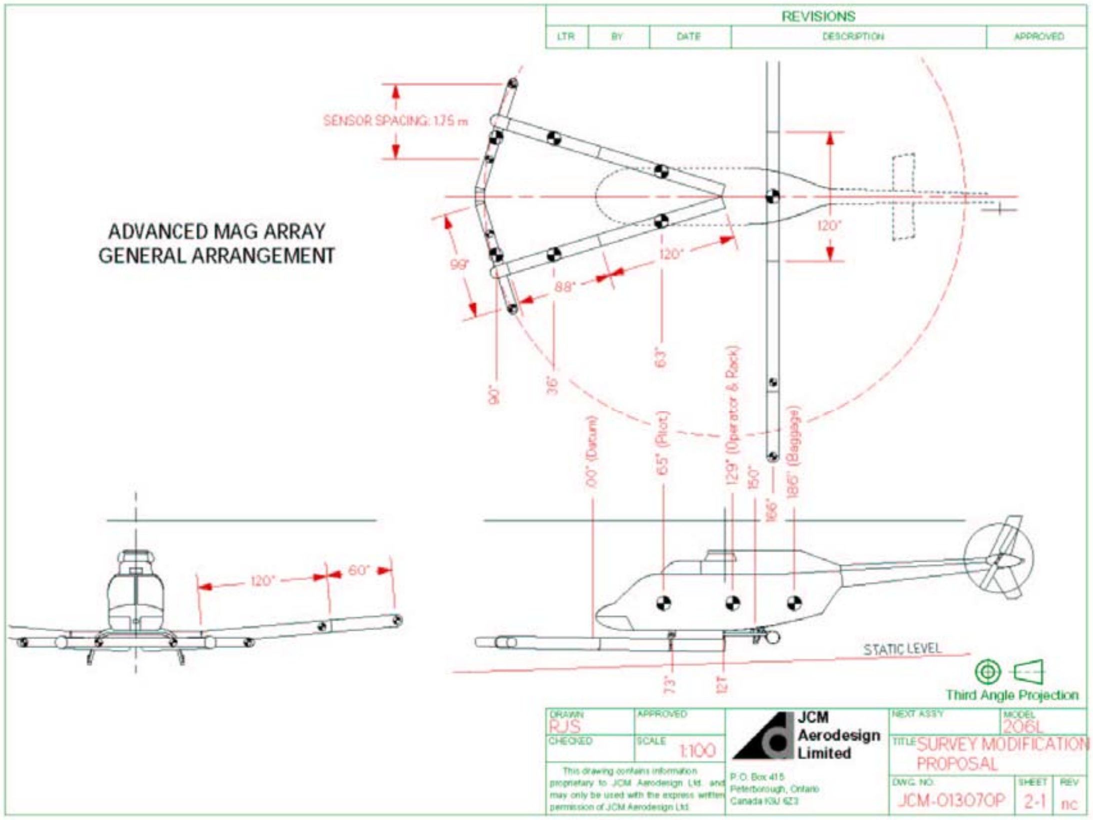

Figure 1. Schematic for the ORAGS-Arrowhead Airborne Total Field Magnetometer System Developed for this Project to Evaluate Improvements over Previous Generations of Total Magnetic Field Systems.

Figure 2. ORAGS–Arrowhead Airborne Magnetometer Platform at APG in Maryland.

This configuration enabled a nominal instrument altitude of 1 to 3 m AGL. Survey lines were directly adjacent to one another so that eight traces of total magnetic field data were collected for each flight line, providing a nominal data profile spacing of 1.7 m with flight line spacing of 12 m. Signal-to-noise performance was enhanced by using 1,200 Hz sample rates with appropriate filters; by closely monitoring and compensating for the pitch, roll, yaw, and flight path of the helicopter; and by correcting the data on the basis of data acquired during a compensation calibration flight. These compensation measurements determine the effects of orientation when the helicopter is the only significant source of magnetic interference.

2.2 PROCESS DESCRIPTION

An operational summary is presented here, with further detail provided in Sections 3 and 4. Mobilization is accomplished by ground transportation of the airborne components, electronic subsystems, and personnel. The helicopter and aircrew are mobilized by air to the base of operations. The base is usually a local or regional airport with suitable security and fuel. The geophysical base stations for GPS and magnetics are established at known civil survey monuments. A processing center is set up at or near the aircraft base of operations.

Installation is conducted by the aircraft mechanic according to Federal Aviation Administration (FAA) requirements and the Supplementary Type Certificate (STC) permit, with support of the ORNL geophysical ground crew. This involves dismounting the tow hook arrangement and installing brackets at these and other hard points in the airframe. The booms, sensors and recording systems are subsequently attached to the bracket mounts and mounted inside the aircraft.

Survey blocks are chosen and boundary coordinates determined. These are entered into the onboard navigation system. Consideration is given to ambient magnetic fields, topography, vegetation, and survey efficiency. After installation, instruments are tested for functionality before and during an initial check flight. Calibration flights are then conducted to determine digital time lags and compensation coefficients required to correct the readings for the magnetic presence of the helicopter.

After calibration, site surveying commences. The pilot and equipment operator are present in the aircraft during survey operations. The operator is responsible for updating and managing the navigation software as well as real-time quality control (QC) of the incoming geophysical data. Surveying continues on a line-by-line basis until the entire block is covered. Depending on the size of the survey area, multiple flights may be required.

At the end of each flight, data are downloaded to a personal computer for QC evaluation. This includes verification of data integrity and quality from all sensor sources. Data from the ground base station instruments for differential GPS and magnetic diurnal corrections are integrated with the airborne data. The data set is analyzed for completeness of areal coverage (no large gaps or nonsurveyed areas) and for consistency of survey altitude throughout the survey block. Lines or areas of unacceptable or missing data are noted and resurveyed as appropriate.

Upon completion of the survey, the data are processed to correct for the effects of digital time lag, selective availability in GPS, magnetic sensor dropouts, compensation for aerodynamic

motion, magnetic diurnal, array balancing, regional magnetic field, helicopter rotor noise, and positioning of individual magnetometers. Magnetic anomalies are analyzed to derive dig lists and interpretive visual products (e.g., maps) depending on the application.

A variety of skilled personnel are required to conduct this type of geophysical survey. The pilot must be trained in low level or "ground effect" flying. The geophysical console operator must be skilled in making real-time decisions regarding data quality in order to conduct immediate re-flights. He must also be intimately familiar with the system in order to diagnose and perform any minor repairs to cabling, electronics, etc. in the field. The processing geophysicist must be familiar with airborne survey operation and data processing in addition to analysis for UXO targets. All crew must be comfortable with safe operations in and around aircraft.

General and site-specific health and safety plans are generated for each survey project. Following the DOE Integrated Safety Management System (ISMS) process, these plans include provisions for general ground safety, extend them using DoD models for UXO site safety, further extend them to encompass airborne operations and then add wholly new considerations for airborne operations in a UXO theatre. The appropriate management at ORNL, the helicopter operator, and the project sponsor approve these health and safety plans.

2.3 PREVIOUS TESTING OF THE TECHNOLOGY

Surveys conducted by ORNL with predecessors to the Arrowhead system are summarized in Table 1. This technology has evolved from traditional mineral exploration survey systems. While the fundamentals of magnetic surveying have not changed, the capabilities for mounting extremely high sensitivity magnetometers in such an inherently noisy platform were not successfully demonstrated until the mid-1990s. By 1997, the three-sensor Helicopter-Mounted Magnetometer Mapping (HM3™) system was the most technologically advanced system with noise reduction capabilities suitable for practical UXO detection.

Table 1. Airborne Surveys Flown by ORNL with Predecessors to the Arrowhead System.

Site	Year	System	Area (Acres)	Area (Ha)
Edwards Air Force Base (AFB)	1997-8	HM-3	1,280	518
BBR	1999	HM-3	287	116
BBR	2000	Hammerhead	201	201
BBR	2000	Hammerhead	~200	
Shumaker	2001	Hammerhead	970	392
BBR	2001	Hammerhead	~200	
Fort Detrick	2001	Hammerhead	365	148
NMLI	2001	Hammerhead	785	318
New Boston	2001	Hammerhead	204	82

Including the HM3™ system, ORNL has previously tested and developed/demonstrated three generations of boom-mounted airborne magnetometer systems for UXO detection and mapping. The HM3™ system depicted in Figure 3 was developed by Aerodat Ltd. under the direction of J.S. Holladay and T. J. Gamey. The 1999 airborne magnetometer tests at Badlands Bombing Range (BBR) deployed this system, operated by High Sense Geophysics, and modified to meet ORNL requirements (Gamey et al., 2000).

Figure 3. The HM-3 Helicopter Magnetometer System Used by ORNL in 1999 for Surveys at BBR.

The Vanguard Geophysics VMA system was a five-sensor array developed by Gamey and Holladay after the financial collapse of Aerodat Ltd. In September 2000, ORNL deployed a more advanced helicopter system at BBR, the ORAGS-Hammerhead system, in cooperation with Dr. Holladay (now at Geosensors Inc., a teaming partner with ORNL) and Mr. Gamey (now at ORNL). While somewhat similar in appearance to the HM3™ system, this system (see photo in Figure 4) is significantly improved in terms of the number of magnetometers, magnetometer spacing, system positioning, navigation, and data acquisition parameters (Doll et al., 2001; Gamey et al., 2001). Additionally, a dihedral in the boom tubes improved system safety by raising the boom tips above ground level.

Figure 4. ORAGS-Hammerhead Airborne Magnetometer System Used at BBR in 2000.

The HM3™ was tested at several locations, including a 1997 ORNL survey at Edwards Air Force Base. In applications from 1999 to 2000, the HM3™ and ORAGS-Hammerhead were successfully used for an ESTCP demonstration at BBR. These demonstrations involved surveys for a variety of ordnance and ordnance-related items at both known and unknown test sites and bombing targets. The Hammerhead system was also used by DoD to survey UXO-contaminated sites at Shumaker Naval Ammunition Depot, Arkansas; Nomans Land Island, Massachusetts, and New Boston Air Station, New Hampshire.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Airborne surveys for UXO are capable of providing data for characterizing potential UXO contamination at a site at considerably lower cost per acre than ground-based systems. Furthermore, the data may be acquired in a shorter period of time. Airborne systems are particularly effective at sites having low-growth vegetation and minimal topographic relief. They can also be used where heavy brush or mud makes it difficult to conduct ground-based surveys.

The performance of the ORAGS-Arrowhead system compares favorably with that of previous airborne magnetometer systems at the same test site. Small targets (e.g., 60mm mortars) have weak but often detectable responses when data are acquired at 1-2 m AGL. Performance under field conditions, particularly at less pristine sites than the BBR test site, will fall short of the performance at the BBR test site. Performance is clearly lower than that of ground surveys (e.g., towed array surveys using MTADS), which can operate with sensors at less than 0.5 m AGL.

Both airborne and ground magnetometer systems are susceptible to interference from magnetic rocks and magnetic soils. Rugged topography or tall vegetation limits the utility of helicopter systems, necessitating survey heights too high to resolve individual UXO items.

The primary advantage of this system is the capability to cover large areas of ground more quickly and cheaply than conventional ground-based surveys. Where large UXO items are involved, the wider sensor spacing and higher altitudes found in airborne arrays result in very little reduction in detection capability. Large UXO such as bombs or large caliber shells have been demonstrated to have spatially large magnetic anomalies with amplitudes easily detectable from typical survey heights. Detection of smaller items, however, is reduced and/or limited as a result of wider sensor spacing and higher altitudes. The airborne system also has an advantage in areas where ground access is limited or difficult due to surface conditions (swamp or marsh) or inherent danger (exposure to UXO or other contaminants). Areas with a sensitive ecological environment may also benefit from the less intrusive airborne technology.

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

Although airborne methods have historically been used to characterize geologic features, recent technological developments have led to an increase in sensitivity that make these methods reasonable for detecting of many types of UXO. The analysis of magnetic data for each project site focused on identifying the locations of surface and near-surface UXO (and ordnance debris) and distinguishing between anomalies that occurred due to natural processes and those that resulted from human activities. Working closely with the USAESCH, ORNL and its team members acquired high-resolution magnetic data in support of identifying and mapping surface and near-surface UXO and ordnance debris within the areas of interest at a number of DoD sites across the U.S. This data acquisition platform and mission flights were characterized by innovative technical criteria, including an extremely low flight altitude, reduced flight line spacing, and higher sample rate. GPS and altitude information were also acquired.

The system was designed for detecting small amounts of man-made ferrous metal (e.g., a few kg of steel or a typical artillery shell) but will also respond to larger man-made magnetic objects or naturally occurring rocks and soils that are magnetic. Simultaneously, real-time differential global positioning system (RT-DGPS) data were acquired to geo-locate the magnetic data. The magnetometer system was mounted on a Bell 206L Long Ranger helicopter and flown at 1 to 3 m AGL. Flight line spacing was approximately 12 m with an aircraft speed of 60 mph. The design of the magnetic sensor array enabled simultaneous acquisition of data along eight lines. This acquisition procedure provided data at 1.7 m line spacing with measurements at intervals of about 0.15 m along each line.

As discussed previously, the objectives of this project centered on demonstrating the usefulness of the technology as a tool to aid in footprint reduction and to help delineate areas of concern for ordnance contamination. Table 2 lists the various performance objectives for these surveys. Sampling anomalies of appropriate sizes indicative of ordnance and explosives use verifies the application. The technology exceeded expectations and successfully identified individual ordnance items including M38 practice bombs; 2.25-inch and 2.75-inch aerial gunnery rockets; 60-mm and 81-mm mortar rounds; 500-lb, 750-lb, and 1,000-lb general purpose air-deployed bombs, as well as the actual locations and boundaries of aerial bombardment targets. The probability of detection (P_d) of these objects varied as expected, with larger items having higher reported P_d.

Table 2. Performance Objectives of the ORAGS-Arrowhead Airborne Magnetic System.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?
Qualitative	System aerodynamically stable	Pilot report	Yes
Quantitative	Lower noise than predecessors	Comparison of data sets at test site and elsewhere	Yes ~0.2 nT after filtering
Qualitative/ Quantitative	Improved aircraft compensation over previous systems	Comparison of figure of merit (FOM) and compensated profiles with those from Hammerhead system data	Yes Hammerhead FOM of 3.8 nT, versus 2.9 nT for Arrowhead, due largely to improvements at positions 2.5 m from centerline
Quantitative	Probability of detection	>90%	Site and ordnance type dependent (see Table 6)
Quantitative	False alarm rate	6% of total picks	Site dependent (see Table 6)
Quantitative	Location accuracy	<100 cm	No
Quantitative	Survey rate	>40 acres/hr	Yes
Quantitative	Percent site coverage	100%	Yes

3.2 SELECTION OF TEST AND SURVEY SITES

A number of demonstration and project survey sites were selected and/or utilized for the project. The demonstration sites are well-documented in a number of ESTCP Demonstration Project reports, while the project surveys are documented in project final reports (ORNL, 2005 a-e). The ESTCP demonstration projects are summarized in Table 3.

Table 3. Surveys with the Arrowhead System for ESTCP.
(summarized in this report).

Project	Sites Surveyed	Total Acres	Total Ha	Ordnance Types	Emplaced Items (if applicable)
APG	Active recovery field (ARF) for indirect-fire weapons; mine, grenade and direct-fire (MGD) weapon range; dewatering ponds (DP) –non-tidal – historically clear of UXO; and Airfield (AF) – historically clear of UXO	348	140	Diverse (14 types: 105 mm, 106 mm, 120 mm, 14 in, 155 mm, 175 mm, 2.75 in, 240 mm, 5 in, 6 in, 75 mm, 8 in, 90 mm, Butterfly Bomb)	2.75 in, 60 mm, 81 mm, 105 mm, 155 mm
BBR	Test grid, Parsons A, Parsons B, Bombing Target 1, and Bouquet Table	272	110	M-38	Diverse (see BBR Final Report)
Pueblo of Laguna	N-09, N-10, N-11, and S-12	4,070	1,647	M-38	N/A
Pueblo of Isleta - 2002	S-01, S-02, and S-07	791	320	M-38	N/A
Pueblo of Isleta - 2003	S-01	1,630	660	M-38, MK-76, 500 lb, 1000 lb, nuclear SIMs, MK-81, MK-83, MK-23, BDU	2.75 in, 60 mm, 81 mm, 105 mm

Survey projects for DoD sites (with funding from entities other than ESTCP) included:

Camp Wellfleet (703 ha/1,736 acres)
Camp Navajo (912 ha/2,253 acres)
Sierra Army Depot (1,876 ha/4,633 acres)

3.3 TEST SITE HISTORY AND CHARACTERISTICS

The demonstration and project survey sites utilized for the project were scattered throughout the United States. Each area ranged from a few hundred acres to several thousand acres in size and were characterized as having generally flat to rolling topography. Some areas have been used or are currently being used for farming and grazing of livestock, while others have only seen military use. Each site was known to contain impact areas and/or targets containing probable ordnance and explosives. The purpose of these surveys, in addition to demonstrating the technology, was to acquire, process, and analyze geophysical data for suspected subsurface ordnance items, ordnance-related artifacts, and buried waste sites. Additional information concerning site history and characteristics can be found in the associated project or final reports for the site and organizational sponsors.

3.4 PHYSICAL CONFIGURATION AND OPERATION

3.4.1 Overall Survey

The demonstrations and surveys were completed between 2001 and 2004. Aircraft ground speed was maintained at an average of approximately 20 m/s (approximately 60 mph) with a mean terrain clearance ranging from 1 to 3 m consistent with the safety of the aircraft and crew. The survey aircraft was a Bell 206L Long Ranger helicopter. Operations were based at the appropriate local, regional, or international airport. The GPS and diurnal monitor base stations were established at locations containing known geodetic markers.

Comprehensive Operational Emergency Response Plan (Site-Specific Health and Safety Plan) were developed for each demonstration or survey project to address issues related to flight operations, safety, and emergency response. Each plan was incorporated into an overall Mission Plan developed to manage field survey operations for each airborne survey operation.

3.4.2 Calibration Test Sites

Each project utilized a controlled calibration test site. These sites ranged from a single regularly spaced line of ordnance items and simulants (e.g. Sierra Army Depot) to an extensively documented site containing dozens of ordnance items, engineered items, and simulants (e.g., Cuny Table Site at BBR). These sites were developed to establish an understanding regarding the capabilities and limitations of the sensor technology, as well as signatures generated by each ordnance-related item. Targets were chosen to bracket expected detection parameters and were known to the investigators in all but the blind test sites. Typical logistics associated with these sites include:

- Establishing a survey grid, typically in the north-south direction, with burial locations placed at approximately 20 m spacing between locations
- Establishing fiduciary data (i.e., dimensions, weights, descriptions) on all items to be buried, including photographs prior to burial
- A preseeding survey of the site using a Geometrics Model G-858 magnetic gradiometer system and sometimes a Geonics EM-61 electromagnetic system to determine the background geology, soil conditions, and the presence/absence of any pre-existing ferrometallic "clutter"
- Excavating the burial sites and subsequently burying the objects of interest in the ground and recording fiduciary data for each buried item, including depth to the top of the item, burial orientation, azimuth, inclination, etc.
- A post-seeding survey of the site, again using the Geometrics Model G-858 and sometimes the Geonics EM-61, to determine ground-based geophysical signatures of each item for comparison to airborne geophysical data and for reacquisition of the items in the future.

3.4.3 Physical Configuration of the Airborne System

The ORAGS-Arrowhead system is arranged with sensors in each of three booms. The GPS antenna is mounted in the forward boom. The booms converge at the hook location underneath the helicopter (the hook is removed to facilitate boom installation). The distance between the GPS antenna and the hook location is 6.1 m, and the distance from the hook to the most distant lateral sensors is 6.1 m. These numbers, plus the aircraft orientation, are required to calculate the position of each sensor.

The laser altimeter is mounted beneath the helicopter, approximately 0.5 m lower than the sensors.

Data are recorded digitally by a new high-speed data acquisition system in a proprietary data format. All raw data are sampled at 1,200 Hz and downsampled to a 120 Hz sample rate. Data are imported into a Geosoft-formatted database for processing. All data processing is conducted using the Geosoft software suite.

The sensors used are Scintrex cesium vapor optically pumped magnetometers with sensitivity of 0.001 nT. A global positioning system is operated in real-time differential mode to control aircraft navigation. The receiver antenna is mounted on the forward boom while a second system acts as the base station. Raw GPS data are collected and post processed for greater accuracy in data positioning.

During flight, magnetic data from the sensors are routed to the onboard console where the raw data are processed into magnetic field strength. The data are filtered to remove high-frequency noise associated with the helicopter; time stamped for correlation to other data streams, and recorded. Data are transcribed into a database post flight where additional processing is conducted.

Because the earth's magnetic field is in a constant state of flux, a base station sensor is established to monitor and record this variation every few seconds. With normal variations, the recorded data are subtracted directly from the airborne data on a point-by-point basis. The time stamps on the airborne and ground units are synchronized to GPS time.

Data are examined in the field to ensure sufficient quality for final processing. The adequacy of the compensation data, heading corrections, time lag, orientation calibration, and data format compatibility are all confirmed during data processing. During survey operations, flight lines are plotted to verify full coverage of the area. Missing lines or areas where data were not captured are rejected and reacquired. Data are also examined for high noise levels, data drop outs, loss of real time differential connection, or other unacceptable conditions.

3.5 PREDEMONSTRATION TESTING AND ANALYSIS

Shakedown testing of the assembled airborne system and associated components was conducted in Toronto, Ontario, Canada, during December 10-21, 2001. These tests were used to determine whether the completed system and its components were performing as designed.

The airborne magnetic system was thoroughly flight tested by an FAA designated engineering representative (DER) and determined to be completely flight-worthy. The testing validated the aerodynamic stability and performance of the system. An STC was issued to allow routine use of the system. Magnetic noise levels for the system were measured on the ground and during flight. Total magnetic field data were collected at low altitude over known targets in a seeded test area.

The test of the ORAGS-Arrowhead total magnetic field array demonstrated a significant reduction in ambient noise in the two sensors located 2.6 m from the centerline of the helicopter without compromising the efficiency of the aerodynamics or the quality of the data from the other sensors. In the presence of the high noise environment of the helicopter, relative noise levels between sensors were used to demonstrate this reduction. The conclusion is that the new sensor positions show a clear reduction in rotor noise relative to the previous array configuration.

In summary, all system components performed as anticipated. The noise at the inboard positions 4.4 m from the centerline of the helicopter is somewhat higher than the noise levels of the other magnetometers, but is reduced over inboard magnetometers from the ORAGS-Hammerhead system at 2.7 m from the centerline. Flight performance and maneuverability were excellent with no ballast required.

3.6 ANALYTICAL PROCEDURES

3.6.1 Operating Parameters for the Technology

The ORAGS-Arrowhead system is designed for daylight operations only. Lines were flown in a generally east-west or north-south pattern depending on local logistics and weather conditions with a nominal 12 m flight line spacing for the high density survey coverage. Binary data from the eight magnetometers were recorded on the console at a rate of 1,200 Hz (samples per second). A typical survey speed for the system was 20 m/s. Average survey height ranged from

1 to 3 m. In areas where background magnetic susceptibility and variation was small, vegetation height low, and topographic change gradual, the system can be expected to detect ordnance such as M38 practice bombs, 105 mm and 155 mm artillery shells, and smaller ordnance as well as fragments and nonordnance items. These thresholds can be expected to increase as any of the aforementioned variables increase.

3.6.2 Experimental Design

The tests conducted with the ORAGS-Arrowhead total magnetic field system are summarized in Table 4. More details are available in the final reports for each site project which can be found in the ESTCP online document library system.

Table 4. Field Tests with ORAGS-Arrowhead Total Magnetic Field System.

Test ID	Description	Parameters	Sites
Standard configuration	Test overall system performance (aerodynamics, noise, compensation, positioning, orientation, detection)	Altitude =ALASA* at each of the four APG sites Alt = 1.5 m at APG calibration grid; ALASA at each of the four BBR sites Alt = 1 m, 10 m at BBR test grid Nominal altitude = 2 m at Isleta 2002 and 2003 and Laguna 2002	As identified in Section 3.2

*as low as safely allowable

The design parameters to be used for this technology demonstration (see Section 4.1, Performance Criteria) focused on prior-generation airborne results as the baseline performance condition, as well as previous Multisensor Towed Array Detection System (MTADS) demonstration data. Progressive improvements can be seen in the development of the technology.

Analysis of early HM-3 data by the Institute for Defense Analyses (Andrews et al., 2001) yielded the following results: 78% to 83% ordnance, 17% to 24% false positives. A subsequent analysis by Scott Holladay of Geosensors confirmed these figures (ORNL, 2002). Subsequent ORAGS-Hammerhead airborne surveys at BBR, Shumaker Naval Ammunition Depot and Rocket Test Range, Nomans Land Island, and New Boston Air Force Station yielded results consistent with the previous surveys at BBR. Positional accuracy of the data improved from approximately 2 m in Hammerhead tests to about 1 m with the Arrowhead system. This we attribute to the fact that by moving sensors 3 and 6 to the forward boom, they were closer to the GPS sensor than in the Hammerhead assembly and less susceptible to mispositioning caused by helicopter yaw.

Metrics for the demonstration of the system approached or met the performance parameters. ORNL expected the ORAGS-Arrowhead total field system to provide detection in the vicinity of 90% ordnance with 5% to 7% false positives. The methodology used to acquire the airborne data are described in previous sections of this document with a variety of altitudes flown. Most of the surveys conducted with the ORAGS-Arrowhead total field system were performed as high-density surveys with line spacing established to account for sensor positions such that no gaps or voids exist in any data set, except where planned. Positioning accuracy for the anomalies detected were just under 100 cm on average.

3.6.2.1 Data Processing Procedures

The 1,200 Hz raw data were de-sampled in the signal processing stage to a 120 Hz recording rate. All other raw data were recorded at a 120 Hz sample rate. Data were converted to an ASCII format and imported into Geosoft formatted databases for processing. With the exception of the differential GPS postprocessing, all data processing was conducted using the Geosoft software suite with specialized modules adapted for our hardware configuration and data format. The quality control, positioning, and magnetic data processing procedures are described below.

3.6.2.2 Quality Control

All data were examined in the field to ensure sufficient data quality for final processing. The adequacy of the compensation data, heading corrections, time lags, orientation calibration, overall performance and noise levels, and data format compatibility were confirmed during data processing. During survey operations, flight lines were plotted to verify full coverage of the area. Missing lines or areas where data were not captured were reacquired. Data were also examined for high noise levels, data dropouts, significant diurnal activity, or other unacceptable conditions. Lines flown, but deemed to be unacceptable for quality reasons, were reflown.

3.6.2.3 Positioning

During flight, the pilot was guided by an onboard navigation system that used real-time satellite-based differential global positioning system (DGPS) positions. This provided sufficient accuracy for data collection (approximately 1 m) but was inadequate for final data positioning. To increase the accuracy of the final data positioning, a base station GPS was established at known geodetic base survey markers at or near each survey location. Raw data in the aircraft and on the ground were collected. Differential corrections were postprocessed to provide increased accuracy in the final data positioning. Final latitude and longitude data were projected onto orthogonal grids using the North American Datum 1983 (NAD 83) Universal Transverse Mercator (UTM) Zone (as appropriate). Vertical positioning was monitored by laser altimeter with an accuracy of 2 cm. No filtering was required of these data, although occasional dropouts were removed.

3.6.2.4 Magnetic Data Processing Procedure

The magnetic data were subjected to several stages of geophysical processing. These stages included correction for time lags, removal of sensor dropouts, compensation for dynamic helicopter effects, removal of diurnal variation, correction for sensor heading error, array balancing, and removal of helicopter rotor noise. Calculation of the magnetic analytic signal was derived from the corrected residual magnetic total field data.

3.6.3 Sampling Procedures

Few of the sites utilized for this project had been previously mapped using ground-based technology. During this demonstration, a significant number of anomalies were excavated to validate performance, as indicated in Table 5.

Table 5. Number of Validation Excavations for Each Site.

Site	Number of Validation Digs
APG	305
BBR	95
Isleta 2002	49*
Isleta 2003	545
Laguna	631
TOTAL DIGS	**1,625**

* In addition to these 49 digs, 337 of the 595 Isleta 2003 digs occurred within the portion of S-01 that was flown in 2002 and were used to assess 2002 performance.

All target anomalies acquired with the airborne system were stored in several Geosoft databases. Each line in the database represented the survey site with the corresponding number. Individual targets were sorted by amplitude and numbered for identification. All peaks over the background noise threshold were selected, with the threshold determined uniquely by inspection of each data set at each site. This threshold typically ranges between 0.2 and 0.5 nT/m. Maps of the target locations were made by plotting colored symbols with ID numbers. The colors corresponded to those used in the analytic signal map.

No attempt was made to deselect anomalies. The purpose here was not to demonstrate the discrimination capabilities of the analytical tools but the detection capabilities of the airborne survey technology.

4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE CRITERIA

Effectiveness of the demonstrations and surveys addressed in these projects is determined directly from comparisons of the processed/analyzed results from the demonstration surveys and the results of previous airborne and ground-based surveys. These comparisons include both the quantitative and qualitative items described in this section, which is documented fully in each project report described in Section 3.2. Demonstration success is determined as the successful acquisition of airborne geophysical data (without any aviation incident or airborne system failure) and meeting the baseline requirements for system performance as established previously in Section 3.1. Methods utilized by ORNL on both current and past airborne acquisitions to ensure airborne survey success include daily quality assurance (QA)/QC checks on all system parameters (GPS, magnetometer operation, data recording, system compensation measurements, etc.) in the acquired data sets, a series of compensation flights at the beginning of each survey, continual inspection of all system hardware and software ensuring optimal performance during the data acquisition phase, and review of data upon completion of each processing phase.

Several factors associated with data acquisition cannot be strictly controlled, such as aircraft altitude and attitude. Altitude is recorded and entered into the data analysis and comparisons with previous results. The aircraft attitude measuring system provides a documented database that cannot be directly compared with previous surveys when this system was not available. The consistent and scientific evaluation of performance is accomplished by using identical or parallel (where parameters are data set dependent) processing methods with identical software to produce a final map, and following consistent procedures in interpretation when comparing new and existing data sets from the respective test sites.

Data processing involves several steps, including GPS postprocessing, compensation, spike removal, removal of magnetic diurnal variations, time lag correction, heading correction, filtering, gradient calculations, and gridding. Each step is performed in the same manner on data acquired with sequential generations of system at the same sites (e.g., BBR), to provide a basis for comparing the performance of the systems. The processing procedures have been selected and developed from experience with similar data over a span of more than 5 years for optimal sensitivity to UXO.

Data quality objectives, as described in Section 3.6.2, were used for these demonstrations and surveys. Surveys over the previously described test areas were conducted as described in Section 3.6. Data collection occurred at various flight altitudes over the various test areas. Data confirmation was in accordance with the processes previously described in this section. Table 6 identifies the expected performance criteria for these projects, complete with expected/desired values (quantitative) and/or definitions and descriptions (qualitative).

Table 6. Performance Criteria and Results for the ORAGS-Arrowhead Airborne Magnetic System.

Performance Criteria	Expected Performance Metric (Pre-demo)	Performance Confirmation Method	Actual Performance (BBR)	Actual Performance (Isleta 2002)	Actual Performance (Laguna)	Actual Performance (APG)	Actual Performance (Isleta 2003)
Primary Criteria (Performance Objectives) – Quantitative							
System performance	Ordnance detection – greater than 90% (1)	Comparison to prior collected airborne and ground-based data	100% (M-38 and larger)	74%	87%	Ranged between 11% and 98%, depending on search radius and site conditions	78% non-seed, 46% seed;
	False positives – less than or equal to 6% (2)	Number of discrimination stage false positives/number of dug clutter items	9.5%	4.4%	13%	Unknown	14% of total excavations were clutter
	Data acquisition rate – greater than or equal to 40 acres/hr	Comparison to prior ORNL-conducted airborne surveys	Up to 62 acres/hr	> 100 acres/hr	> 140 acres/hr	91 acres/hr averaged over APG sites	96 acres/hr
	Detection threshold (sensitivity)	Comparison to prior collected ground-based geophysical data	~3 nT/m for reliable detection	~5 nT/m for reliable detection	~5-7 nT/m for reliable detection	Variable, dependent upon altitude	~5 nT/m for reliable detection
System performance	Anomaly positional accuracy (3)	Comparison to known benchmarks and known, documented anomalies at the test site locations	<1.0 m (~96 cm)	~1.0 m	<1.0 m (~85-90 cm)	<1 m varying with search radius	Avg 103 cm Standard deviation (Stdev) 45 cm At 2 m search radius
	High frequency helicopter noise <0.1 nT	Average peak-peak across array at high alt after filtering	0.1-0.2 nT	0.1 nT	0.6 nT raw (approx 0.05 nT filt)	0.3 nT	0.9 nT raw (~0.1 nT filt)
	Low frequency helicopter noise <10 nT	Calculation of FOM	2.6 nT	2.6 nT	11.8 nT	18.9 nT	2.9 nT
Primary Criteria (Performance Objectives) – Qualitative							
Process waste	None	Observations	No process waste				

Table 6. Performance Criteria and Results for the ORAGS-Arrowhead Airborne Magnetic System (continued)**.**

Secondary Criteria (Performance Objectives) – Quantitative			
Hazardous Materials	None expected	Observations and documentation during excavations	None
Secondary Criteria (Performance Objectives) – Qualitative			
Reliability	No system or component failures	Observations and documentation	No components failed during the total field surveys
Ease of Use	Pilot "comfort" when flying with the system installed	Observations and documentation	Pilot states that he feels at ease flying the system under normal wind conditions
Ease of Use	No ballast required	Observations and documentation	Engineer declared the system balanced without need for ballast
Safety	Conformance with all FAA requirements and requirements documented in the Mission Plan	Observations and documentation	System met all FAA flightworthiness requirements
Maintenance	System mount points, hardware, and component inspection	Observations and documentation	Minimal wear and tear

(1) We define the term "ordnance detection" to mean the percentage of ordnance items as large as or larger than 81-mm mortar rounds that produced magnetic anomalies discernable above the noise floor and within a defined search radius. The term does not imply that the anomalies were or were not correctly classified.

(2) The term "false positive" we take to mean discrimination stage false positive, i.e. an anomaly produced by clutter within a given search radius that was incorrectly predicted to be ordnance.

(3) By the term "anomaly positional accuracy" we mean the distance between the documented UXO or clutter item location and the location predicted by the geophysical anomaly or its inversion.

4.2 DATA ANALYSIS, INTERPRETATION, AND EVALUATION

The ORAGS-Arrowhead magnetometer system does not distinguish between UXO and ferrous scrap for the many anomalies mapped without interpretation. The total field and analytic signal maps provided in this report depict bombing targets (areas of high ordnance density), infrastructure (fences or larger items or areas of ferrous debris associated with human activity), and potential UXO items (discrete sources). Those responses, interpreted as potential UXO, likely also include smaller pieces of ferrous debris. Additional analysis and interpretation of the survey results are included in each final project report.

4.2.1 System Noise

The noise performance of the Arrowhead system showed significant improvement over that of its predecessor, the Hammerhead system, due largely to the relocation of magnetometers positioned 2.55 m from the helicopter's centerline. These sensors were on the rear boom in the Hammerhead design and were moved to the new front boom structure in the Arrowhead. In the Hammerhead, the system FOM was 3.8 nT, with sensors 3 and 6 at 8.1 nT. The FOM for sensors 3 and 6 was reduced to 2.9 nT in the Arrowhead, resulting in an overall FOM of 2.6 nT.

4.2.2 Positional Accuracy

Positional accuracy is summarized in Table 6, with details provided in the respective final reports. It is estimated for each project by comparison of predicted dig locations, chosen from the peak value of the analytic signal anomaly or by inversion using the data analysis system (DAS) code, with actual position of emplaced or dug items, as reported by the ESTCP, the project sponsor, or validation contractors. Mean positional errors were determined for the defined search radii and for specific detection algorithms as utilized by each respective project. These are tabulated and presented in the respective project reports and are summarized in Table 6. The positioning errors averaged about 1 m at all sites, varying somewhat with the search radius and detection algorithm.

4.2.3 Altitude

Survey altitude varied with topography, surface conditions, wind, and other flight conditions along each survey line. Each project database contains data points at altitudes too high for standard UXO detection during turnarounds or other maneuvers. In general, to capture representative altitudes for each survey area, higher altitude points are either highlighted or removed from the data set. Average altitudes are then calculated from the remaining data points. Among the sites evaluated in this project, altitude was of greatest significance at APG, and least important at BBR. Topography and vegetation caused data to be acquired at higher altitudes at APG, whereas these conditions as well as favorable wind conditions enabled operation at lower altitudes at BBR.

4.2.4 Site-Specific Performance Evaluation

One of the most critical performance criteria for this project is the detection capability of the system. This was observed to vary as a function of site conditions, ordnance types at each site, and validation approach.

At BBR, the ORAGS-Arrowhead system proved adequate for defining zones in former test ranges where bombing activities have occurred. Peak-to-peak noise levels in the raw magnetic data, including blade and rotor noise, ranged from 1-6 nT. When filters were applied to noise induced by the blades and rotor, noise levels were reduced to 0.1-0.2 nT in all sensors. In a 61 m x 61 m excavation plot in Parsons Area A, the locations of 100% of all ordnance (M-38 practice bombs and a live 100-lb high-explosive bomb) were accurately delimited (Van et al., 2004). A subsequent ground magnetic survey of the area turned up some additional UXO fragments but no additional intact ordnance. Nine false positives (non-UXO or no finds) occurred in 95 samples, for a false positive rate of 9.5%.

At Pueblo of Isleta in 2002, peak-to-peak noise levels in the raw magnetic data were within 1 nT in 5 of 8 sensors. In the two inboard sensors of the rear booms, noise levels exceeded 1 nT but were less than 2 nT. When filters were applied to noise induced by the blades and rotor, noise levels were reduced to 0.1-0.2 nT in all sensors. At site S-01, results show that in 18 dig locations where UXO fragments were found, the Arrowhead system correctly predicted 17 of these. Of the ORAGS detections that were dug in S-01, 39%were classed as “no finds.” This value is high in comparison to other surveys, for example, <3% at BBR (Van et al., 2004).

Localized zones of rock or soil with high magnetic susceptibility (hot rock/dirt) may be partly the cause of the high rate of no finds in area S-02.

At Pueblo of Laguna, the peak-to-peak noise levels were equivalent to those in the Isleta 2002 survey, which was conducted in the same deployment. Dig results show that the Arrowhead system detected only about 65-75% of the UXO fragments that were detectable with the MTADS ground magnetic system. However, the sources of most of the airborne anomalies (>85%) proved to be UXO fragments, with a relatively small percentage of no-finds.

At APG, the performance of the ORAGS-Arrowhead total field magnetometer system was lower than experienced at other sites where we have worked. We credit this in part to higher flight altitudes, particularly at the MGD and DP sites, and to somewhat higher noise levels. Over all sites, the altitudes were more variable than we typically experience. Flight altitudes are left to pilot judgment as a safety issue, and we must assume that the pilot felt that it was inappropriate to fly as low at APG as at other sites. Locations of many of the emplaced items coincided with portions of the survey area where data acquisition was particularly high, leading to even poorer performance assessments. Mean anomaly position errors were less than 1 m. At the larger areas surveyed (DP and MGD), the ORAGS-Arrowhead system was able to collect data at a rate in excess of 100 acres/hr, a figure that includes turnaround time at the ends of lines. This is typical of acquisition rates we have achieved in “production” surveys at other sites. Lower acquisition rates (70 and 78 acres/hr) were achieved at the two smaller sites at the ARF and AF sites, which is consistent with our experience for such small targets. Peak-to-peak noise levels in the raw magnetic data were within 1 nT in 6 of 8 sensors. In the two inboard sensors of the rear booms, noise levels were about 2 nT. When filters were applied to noise induced by the blades and rotor, noise levels were reduced to 0.1-0.2 nT in all sensors. Performance as a function of ordnance type, based on a statistical picking procedure and using a 2 m search radius is summarized in Table 7.

Table 7. APG Dig Results for 2 m Search Radius by Ordnance Type.

Area	Class	Classification	Type	Found	Total	Rate	Avg Error	Avg Priority
ARF	Dig	C	Frag	59	60	98%	0.60	2.69
ARF	Dig	C	Scrap	18	18	100%	0.56	2.78
ARF	Dig	Ordnance	105 mm	1	1	100%	0.80	1.00
ARF	Dig	Ordnance	105 mm - partial	1	1	100%	0.04	4.00
ARF	Dig	Ordnance	106 mm	1	1	100%	0.09	4.00
ARF	Dig	Ordnance	120 mm	4	4	100%	0.38	3.25
ARF	Dig	Ordnance	14 in	1	1	100%	0.25	4.00
ARF	Dig	Ordnance	155 mm	17	17	100%	0.60	2.65
ARF	Dig	Ordnance	175 mm	1	1	100%	0.23	2.00
ARF	Dig	Ordnance	2.75 in rocket	1	1	100%	0.72	3.00
ARF	Dig	Ordnance	240 mm	1	1	100%	0.49	3.00
ARF	Dig	Ordnance	5 in	2	2	100%	0.28	3.00
ARF	Dig	Ordnance	6 in	1	1	100%	0.24	2.00
ARF	Dig	Ordnance	75 mm	3	3	100%	0.55	3.00
ARF	Dig	Ordnance	8 in	3	3	100%	0.62	3.33
ARF	Dig	Ordnance	90 mm	9	10	90%	0.76	2.78

Table 7. APG Dig Results for 2m Search Radius by Ordnance Type (continued)**.**

Area	Class	Classification	Type	Found	Total	Rate	Avg Error	Avg Priority
ARF	Dig	Ordnance	90 mm - partial	2	2	100%	1.12	1.00
ARF	Dig	Ordnance	Butterfly Bomb	1	1	100%	0.54	2.00
ARF	Seed	Ordnance	105 mm	6	32	19%	0.92	3.67
ARF	Seed	Ordnance	81 mm	5	32	16%	1.01	4.20
AF	Calib	Ordnance	105 mm	2	2	100%	0.53	2.00
AF	Calib	Ordnance	155 mm	2	2	100%	0.83	2.00
AF	Calib	Ordnance	2.75 in	2	2	100%	1.24	1.50
AF	Calib	Ordnance	60 mm	1	2	50%	0.67	2.00
AF	Calib	Ordnance	81 mm	2	2	100%	0.87	2.00
AF	Seed	Ordnance	105 mm	22	28	79%	0.81	3.09
AF	Seed	Ordnance	60 mm	2	3	67%	0.74	4.00
AF	Seed	Ordnance	81 mm	5	21	24%	0.78	2.80

Although dig procedures that were used at APG do not allow calculation of false positives and false negatives, we can address the effectiveness of the sorting routines that were used. Anomalies were categorized as 1-6, following procedures recommended by ESTCP. For the univariate picking procedure and 2 m search radius, 47.5% of the ordnance items detected were identified as category 1 or 2 (most-likely or probably UXO); 46.7% were identified as category 3 or 4 (possibly UXO or possibly scrap); and only 5.7 were identified as category 5 or 6 (most-likely or probably scrap). Similarly for ordnance fragments, using the same picking routine and search radius, 35.7% were identified as category 1 or 2; 57.8% were identified as category 3 or 4; and 11.4% were identified as category 5 or 6. For scrap, 48.6% were identified as category 1 or 2; 45.7% were identified as category 3 or 4, and 5.7% were identified as category 5 or 6. These results demonstrate that either the anomalies from scrap and UXO are too similar to distinguish between them, or that the library from which the statistical sorting parameters were chosen was inadequate, either in lacking an acceptable distribution of ordnance and nonordnance items or in the types of ordnance that were used to select the parameters. As these sorting routines were new to us and we had little data to develop a library, this is not a surprising result. Improvements can be made in the statistical sorting procedures by incorporating the validation data acquired at APG.

Finally, at Pueblo of Isleta in 2003, the peak-to-peak noise levels in the raw magnetic data were at or less than 1 nT in 6 of 8 sensors. In sensors 2 and 6 (the port inboard sensor of the rear boom and the outer starboard forward sensor), noise levels were in the range of 1-2 nT. Once filters were applied to noise induced by the blades and rotor, noise levels were reduced to ~0.2 nT or less in all sensors. Overall, the system performance was less than most surveys with an average detection rate of 70% as compared to the expected 90%. The performance results for this demonstration as a function of ordnance type with 2 m search radius are summarized in Table 8.

Table 8. Isleta 2003 Detection Results by Ordnance Type.

Area	Class	Type	Item	Found	Total	Rate	Pos Error	Error Stdev
3 sys	dig	Clutter	Geology	28	39	72%	1.07	0.43
3 sys	dig	Clutter	Scrap	35	49	71%	0.97	0.36
3 sys	dig	Ordnance	Frag	56	65	86%	0.98	0.43
3 sys	dig	Ordnance	1,000 lb bomb	1	1	100%	0.59	0.00
3 sys	dig	Ordnance	500 lb bomb	1	1	100%	0.24	0.00
3 sys	dig	Ordnance	BDU	1	1	100%	1.83	0.00
3 sys	dig	Ordnance	Missile comp	1	1	100%	1.20	0.00
3 sys	dig	Ordnance	MK-76	4	4	100%	1.05	0.56
Air	dig	Clutter	Geology	3	4	75%	1.33	0.24
Air	dig	Clutter	Scrap	9	11	82%	1.32	0.41
Air	dig	Ordnance	Frag	146	191	76%	1.04	0.45
Air	dig	Ordnance	1000 lb bomb	2	2	100%	1.01	0.13
Air	dig	Ordnance	500 lb bomb	6	8	75%	0.91	0.54
Air	dig	Ordnance	Burster cup	0	1	0%	0.00	0.00
Air	dig	Ordnance	M38	3	4	75%	0.92	0.53
Air	dig	Ordnance	Missile w/h	1	1	100%	1.05	0.00
Air	dig	Ordnance	MK-23	1	1	100%	0.69	0.00
Air	dig	Ordnance	MK-76	29	43	67%	0.95	0.42
Air	dig	Ordnance	MK-81	1	1	100%	1.53	0.00
Air	dig	Ordnance	MK-83	1	1	100%	0.73	0.00
Air	dig	Ordnance	Nuclear SIM	3	4	75%	1.16	0.45
Air	seed	Ordnance	105 mm	22	40	55%	1.12	0.46
Air	seed	Ordnance	2.75 in	8	12	67%	0.95	0.64
Air	seed	Ordnance	60 mm	6	20	30%	1.20	0.43
Air	seed	Ordnance	81 mm	15	40	38%	1.17	0.38

4.3 TECHNICAL CONCLUSIONS

The ORAGS-Arrowhead airborne system used in these demonstrations and survey projects may be compared with the ORAGS-Hammerhead airborne system and MTADS ground-based magnetic system, which were previously used at several of the sites. The ORAGS-Arrowhead system compares directly and very favorably in a number of ways to these systems. They can be directly compared in many areas including site coverage, detection limits, location accuracy, production rates, and costs associated with deployment and application. Both the 1999 Cost and Performance Report for the ESTCP project, "Evaluation of Footprint Reduction Methodology at the Cuny Table in the Former Badlands Bombing Range" and a report from the Institute for Defense Analyses (IDA), "Review of Unexploded Ordnance Detection Demonstrations at the Badlands Bombing Range – Naval Research Laboratory (NRL) MTADS and ORNL High-Sense HM3^{TM}," provide background information used for this comparison.

In terms of site coverage, the ORAGS-Arrowhead array collects data at about 0.15 m along-line intervals and 1.7 m data line spacing, which compares directly to the ORAGS-Hammerhead system. Detection limits were reached with the inclusion of deeper and smaller test items, which

successfully bracketed the ORAGS-Arrowhead detection capabilities. A background noise level of 0.2-0.5 nT/m was established over the demonstration and survey projects. This represents an improvement over the previous system, mostly by virtue of the improved sensor configuration, denser data sampling, and more sophisticated picking routines.

Tables 7 and 8, combined with the results from BBR, show that the system typically achieves detection rates of better than 70% for larger ordnance, while rates of 30-70% are more typical for 60 mm, 81 mm, and smaller items. The performance is always site-dependent, as demonstrated by the high performance at BBR. In several instances, the performance of the ORAGS-Arrowhead system was lower than experienced at other sites. Previous validation results were based on different procedures, and under different site conditions, with other types of ordnance causing contamination. In some cases, the differences were the result of higher flight altitudes, particularly at sites with more variable terrain or taller vegetation and somewhat higher noise levels. At APG, performance was diminished by a combination of higher vegetation or other altitude limitations, smaller and in many cases more concentrated ordnance, and greater helicopter rotor noise. At BBR, validation indicated better performance than in earlier Hammerhead surveys at other ranges at that site and better performance than at any other sites in this study, affirming that the Arrowhead is superior to its predecessor, the Hammerhead system. Overall, mean positional errors were typically less than 1 m, when a 2 m search radius was used. At the larger areas surveyed, the ORAGS-Arrowhead system was able to collect data at rates in excess of 100 acres/hr, a figure that includes turnaround time at the ends of the survey lines. This is representative of acquisition rates ranging from 50 to 100 acres/hr for “production” surveys at most sites. In general, peak-to-peak noise levels in the raw magnetic data were within 1 nT in 6 of 8 sensors. Typically, for the inboard sensors of the rear booms, noise levels were about 2 nT. When filters were applied to noise induced by the blades and rotor, noise levels were reduced to 0.1-0.2 nT in all sensors.

Although validation procedures varied from project-to-project and site-to-site, they generally did not allow calculation of false positives and false negatives, which are needed to completely address the effectiveness of the sorting and picking routines used.

5.0 COST ASSESSMENT

5.1 FACTORS AFFECTING COST AND PERFORMANCE

The cost of an airborne survey depends on many factors, including:

- Helicopter service costs, which depend on the cost of ferrying the aircraft to the site, fuel costs, terrain, and vegetation conditions impacting flight line configuration, turnaround, etc.
- Total size of the blocks to be surveyed
- Length of flight lines
- Extent of topographic irregularities or vegetation that can influence flight variations and performance
- Ordnance objectives that dictate survey altitude and number of flight lines
- Temperature and season, which control the number of hours that can be flown each day
- Location of the site, which can influence the cost of logistics
- Number of sensors and their spacing—systems with too few sensors may require more flying, particularly if they require interleaving of flight lines
- Survey objectives and density of coverage, specifically high density for individual ordnance detection versus transects for target/impact area delineation and footprint reduction.

5.2 PROJECT COSTS

The total capital equipment cost for the ORAGS-Arrowhead system was approximately $282,300. The total cost of the demonstration and survey projects listed in Section 3.2 was $1,258,703, derived from figures in Table 10. Cost information associated with each survey and demonstration of the ORAGS-Arrowhead technology, as well as associated activities, were closely tracked and documented before, during, and after the demonstration to provide a basis for determining the operational costs associated with this technology. These specific operational costs, represented by a number of survey projects supported by several DoD organizations and facilities, are contained in the respective survey projects final reports. While the development of the ORAGS-Arrowhead technology was generally treated as a research project, several production surveys were included, as they provided much-needed information concerning survey scale-up and large-scale technology application.

As outlined above, it is important to note that the costs for airborne surveys are very much dependent on the character, size, and conditions at each site; ordnance objectives of the survey (e.g., flight altitude); type of survey conducted (e.g., high-density or transects); and technology employed for the survey (e.g., total field magnetic). As such, a universal formula for project costing cannot be fully developed. For these demonstration projects, Table 9 contains the capital cost elements that were tracked and documented for these demonstrations. These costs include

only the capital costs associated with system development, design, and construction. All costs associated with the components of demonstration and production surveys—including mobilization, data acquisition, processing, analysis, interpretation, demobilization, reporting, and project management—are contained in the site-specific final project reports listed in Section 3.2.

Table 9. Approximate ORAGS-Arrowhead Capital Equipment Cost in FY02.

Cost Category	Subcategory	Quantity	Total Cost
Capital equipment	Cesium-vapor magnetometers	8	$122,200
	GPS	1	$15,500
	Booms and mounting hardware	1	$36,500
	Orientation system	1	$16,600
	Fluxgate magnetometer	1	$5,300
	Navigation system	1	$5,200
	Laser altimeter	1	$7,300
	Data management console	1	$31,200
	Magnetic base station	1	$15,100
	GPS base station	1	$15,600
	PCs for data processing and analysis	2	$3,450
	Shipping cases	6	$4,750
	Trailer	1	$3,600
Total Costs			$282,300

5.3 TYPICAL AIRBORNE SURVEY COSTS

Table 10 represents costs associated with the airborne-based technology in full production implementation. These surveys range in size from 247 acres to more than 4,070 acres. All costs represented in the table are costs that were incurred for a production survey at an actual site contaminated with ordnance, for analysis of those data, and for generation of the map products and dig lists. They do not reflect the full cost associated with the demonstration of an innovative technology, particularly costs associated with excavation for ground-truthing and verification.

Table 10. Actual Costs for ORAGS-Arrowhead Technology Demonstrations and Surveys.

Site	Size (in acres)	Total Survey Cost	Cost per Acre
BBR	272	$159,096	$585
Pueblo of Laguna 2002	4,070	$348,080	$86
Pueblo of Isleta 2002	773	$168,566	$218
Pueblo of Isleta 2003	1,630	$337,864	$207
APG	348	$245,097	$704

Also of note, no one-time, demonstration-related costs associated with survey optimization, detailed calibration site analysis, nonroutine analysis, or excessive reflights over the survey areas to evaluate and/or refine the demonstration are included in the costs outlined in the table. It should be noted that survey efficiency and cost are improved as the size of the survey area increases.

Often, specific survey sites and parameters are unknown or ill-defined during the early stages of project planning when consideration is being given to which geophysical technology is most suitable. With this in mind, combined with the results of the identified production surveys, a typical set of cost estimates were developed that could be utilized for project planning purposes. These cost estimates were based on cost models for conducting similar airborne magnetometer surveys, as well as incorporating lessons learned and final project costs from similar past projects at the sites listed in Section 3.2. While initial calculations of survey costs included a variable associated with geographic locale, it was determined that this variable was actually a constant (approximately) due to the offsetting of ORNL mobilization/demobilization costs and the ferry time for a regional helicopter provider to mobilize/demobilize from the survey sites. In addition, the survey cost estimate models assume surveys are conducted over relatively large contiguous areas. Surveys conducted over areas less than 1,000 acres are not reflected in these cost models and require a different estimation structure.

These generic cost estimates include the following factors:

- Project management
- Mobilization/demobilization of the applicable airborne technology
- Data acquisition (including equipment and helicopter costs)
- Data processing, analysis, and interpretation
- Reporting
- Travel, materials, and miscellaneous expenses
- Federal acquisition cost—3% congressionally-mandated administrative fee to DOE
- A project contingency of 5% to account for weather, etc.

5.4 COST ANALYSIS

The major cost driver for an airborne survey system is the cost of helicopter airtime. In terms of tasks, this constitutes the majority of the data acquisition costs – the single largest cost item.

Data processing and analysis functions make up the bulk of the remaining costs. The costs associated with developing robust processing algorithms were a major factor in this project. This is expected to diminish with each project as solutions to common scenarios are found. Mobilization is also a major task in terms of cost. Generally, this is a function of distance from the home base for the helicopter and equipment. Peripheral costs associated with this demonstration-validation project, such as ground truth and excavations *were not* considered in this part of the cost analysis.

The sensitivity of the overall cost to these drivers can be modeled under several different scenarios. Helicopter time on site is a factor of several variables, the first being the number and dimensions of the survey blocks. The greatest amount of nonsurvey time is spent in turns at the end of each line in preparation and alignment for the next line. Fewer and longer survey lines

are therefore more efficient than numerous shorter ones. Typically, lines longer than approximately 8-10 km do not gain additional efficiencies. One mitigating factor to this limit is a pilot performance issue. Longer lines typically require more frequent reflights, since it is more difficult to maintain precision flying over such long lines. In practice, a maximum line length of 5 km is advised.

The other major cost drivers were data processing and mobilization/demobilization. Processing and mobilization costs are generally linear with project size and transportation distance, respectively. Processing costs and data deliverable times will decrease with experience at multiple sites. Continued and consistent use of a static technology could potentially lead to overnight delivery times. Mobilization costs are unlikely to decrease with time. The use of a local helicopter and pilot may offer decreased mobilization costs, but risks significantly increase in acquisition costs if the mechanic in charge of installation is unfamiliar with the equipment, or if the pilot is uncomfortable with the level of precision flying required. Moreover, this approach would probably bear higher risk of accidents, and for this reason is unacceptable.

5.5 COST COMPARISONS

This section compares costs of three different survey technologies. These include man-portable, the ground-based MTADS system, and the ORAGS-Arrowhead airborne system.

Based on several sources of information regarding the deployment of ground-based towed array systems on a UXO contaminated site, five scenarios are presented for the purpose of comparing airborne surveys to ground-based surveys. These sources of information are generally informal and include discussions both with industry and USAESCH staff experienced in the application of ground-based towed array surveying equipment and projects.

Comparisons between airborne and ground-based man-portable magnetometer surveys are summarized in Table 11. These scenarios address sites of 1,000 to 50,000 acres of geographic extent, with respective estimated costs of $53 to $98 per acre for the airborne survey portion of the cost comparison. These costs do not include mobilization, which is geographically variable, but may be as high as $75,000 for those sites furthest from our bases of operation in Tennessee and Ontario. They are corroborated by recent work for non-ESTCP sponsors, e.g. the survey at Sierra Army Depot, which covered approximately 4,600 acres at $84 per acre, including mobilization. Man-portable systems generally have significantly higher acquisition costs than airborne systems (ranging from as low as $500 to more than $3,000 per acre, depending on site conditions), are extremely time-consuming, and may present risks to personnel, equipment, and the environment. Neither the airborne nor the ground-based survey costs include the cost of excavation.

Table 11. Cost Savings Between Airborne and Man-Portable Survey Costs.

Area (acres)	Airborne Cost ($/acre)	Airborne Total	Ground Cost ($/acre)	Ground Total	Savings
1,000	98	$98,000	1,000	$1,000,000	$902,000
2,000	78	$156,000	1,000	$2,000,000	$1,844,000
5,000	63	$315,000	1,000	$5,000,000	$4,685,000
20,000	59	$1,180,000	1,000	$20,000,000	$18,882,000
50,000	53	$2,650,000	1,000	$50,000,000	$47,350,000

Although both simplistic and generalized in nature, it is readily apparent that the advantage of airborne surveys over ground-based becomes greater as the area of concern becomes larger.

Even closer to the ORAGS-Arrowhead array are the costs associated with the previous ORAGS-Hammerhead ESTCP demonstrations and DoD surveys. The cost factors involved in the ORAGS-Hammerhead and ORAGS-Arrowhead surveys are very similar. Apart from the learning curve associated with field experience, only the rate of survey coverage has changed significantly between the two generations of the technology. The ORAGS-Hammerhead survey coverage was based on 12 m flight line spacing, which is virtually the same as the ORAGS-Arrowhead.

5.6 COST CONCLUSIONS

As demonstrated above, comparing costs of fundamentally different technology approaches is both difficult and inconclusive. The previously discussed cost comparison provided a range of answers to the same question, namely, what are the costs of deploying each technology over the same size area under the same conditions?

For consideration of DoD-wide application of the airborne technology, a number of factors must be considered when evaluating the appropriateness of the airborne technology and potential for substantial cost savings. While initially impressive, it is not possible to simply apply these types of cost savings across the entire DoD UXO program. Sites must be of sufficient geographic extent to warrant a deployment given the high costs associated with mobilization and demobilization. Terrain, geology, and vegetation must also be considered for such a deployment. Extremely variable terrain or the presence of tall vegetation can greatly limit or impede the use of the airborne technology for the UXO objectives of interest. Finally, the project objective must be consistent with the detection limits and capabilities of the airborne system to make such a deployment feasible.

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6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

Costs for system development, design, and construction as well as each of the demonstration and production survey projects were largely within the original estimates. For the demonstration and production survey projects, data acquisition, processing and analysis tasks generally consumed approximately 60% of the funding. In several cases, demonstration and survey projects were able to leverage mobilization costs to reduce the total expenditures. In the specific case of the BBR production survey, the project leveraged costs from the engineering evaluation/cost assessment (EE/CA) work being conducted by Parsons Engineering Science in addition to testing a prototype airborne electromagnetic system funded under a separate ESTCP project.

Additional cost savings occur in the data processing and analysis tasks. The continued and consistent use of a reasonably static technology is reducing most of the processing procedures to a semi-automated technique. Under these conditions, rapid delivery of survey results is possible and occurred on several projects outlined in Section 3.2. It is important to note that this only applies to a production system used at a large site containing thousands of ordnance and ordnance-related artifacts. In a research platform, continued modifications to the system or new improvements to the processing methods will largely negate this benefit.

6.2 PERFORMANCE OBSERVATIONS

The primary performance objectives were generally exceeded in the demonstration projects and production surveys. Practical survey heights were typically as expected, allowing high resolution of the detected targets and anomalies. Geophysical test grids and calibration sites were established and utilized with the objective of bracketing the detection capabilities of the system by placing smaller and deeper items than those placed in previous demonstrations and surveys.

The objective of this project was to demonstrate detection of ferrous targets, whether ordnance or nonordnance. Classification of anomalies in six categories, specified by the ESTCP Program Office, was incorporated into our interpretation procedure. This made ground follow-up easier to analyze with traditional UXO techniques. False positives were determined to range from 4.4% to 14%, with this largely a measure of system and survey noise and not a robust assessment of discrimination (as is usually the case with UXO surveys). False positives were generally greater at mixed ordnance sites than at sites where a single ordnance type predominated. Ground follow-up at one site (BBR) demonstrated no conclusive false negative responses. This cannot be extrapolated to other surveys nor does it represent a statisticallyvalid result for general airborne surveys.

6.3 SCALE-UP

Scale-up of operations has been successfully achieved, as illustrated through the production surveys of large sites. The current technology requires minor hardware and firmware modifications to improve aircraft and data positioning. Preliminary training materials for geophysical personnel to enable them to conduct the data processing, analysis, and interpretation tasks have been developed. Methodologies for semi-automated selection and classification of

anomalies at large sites containing thousands of anomalies have been proposed for development under an ESTCP project. Given the current market conditions, equipment availability should not be an issue. A single operating airborne system should be sufficient to handle all available work for the foreseeable future. At present, qualified personnel continue to represent a modest obstacle.

6.4 OTHER SIGNIFICANT OBSERVATIONS

As mentioned previously, major factors in implementing or deploying the airborne system are topography and vegetation. Steep topographic variations make it difficult to achieve uniform altitude across many survey areas. Most topographic features will be coherent between lines, which makes them easy to identify and will not be confused with ordnance signatures. The impact on data quality is that the average altitude will increase, making it more difficult to detect smaller objects.

Vegetation has a similar effect on data quality in that it necessitates an increase in survey altitude. Isolated pockets of vegetation or single trees can be handled in two ways. The first is to fly over them and create a small pocket of lower resolution data. The second is to fly around them and create a minor gap in data coverage. Continuous stretches of vegetation or forest should be avoided.

Geologic influence is another factor impacting the technology implementation. The difficulty of detecting ordnance in highly magnetic environments is well documented and impacts the airborne system as it would a ground system.

6.5 LESSONS LEARNED

The primary benefit of this technology is in rapid reconnaissance of large open areas, commonly referred to as footprint reduction. Cost analysis shows that costs per acre decrease significantly as the size of the project increases, whereas ground surveys tend to have a fixed cost per acre. These demonstrations and surveys have proven it prudent to survey as large an area as possible with each mobilization, even if all the data are not processed immediately.

6.6 END-USER ISSUES

End users have been included in the project as often as possible. The USAESCH innovative technology director served as one of the project Principal Investigators; various Native American tribes (land-owners) have been included in the project conception and preparation; and the private sector (e.g., Parsons Engineering Science) supported the ground truth and anomaly investigation (sometimes in parallel to their own field activities). ORNL staff have trained private sector geophysicists to handle airborne magnetic data processing and analysis. All these parties have been supportive and encouraged by the results of these demonstrations and production surveys. In particular, the technicians responsible for the excavations have expressed their admiration for the positioning accuracy of the results.

6.7 APPROACHES TO REGULATORY COMPLIANCE AND ACCEPTANCE

It is important to recognize the different aspects associated with the regulatory involvement in both the technology and the application of the technology to a UXO-contaminated site. With

regard to the application of the technology, there are issues associated with regulatory drivers and involvement of both regulatory entities and other stakeholders that are relevant.

Although no specific regulatory drivers exist at this time for UXO-contaminated land, UXO clearance is generally conducted under CERCLA authority. Additionally, a draft EPA policy is currently under review. Regardless of a lack of specific regulatory drivers, many DoD sites and installations are aggressively pursuing innovative technologies to address a variety of issues associated with ordnance and ordnance-related artifacts (e.g., burial sites) that resulted from weapons testing or training activities. These issues include footprint reduction and site characterization, areas of particular focus for this technology demonstration and associated production surveys. In many cases, the prevailing concerns at these sites become a focus for the application of innovative technologies in advance of anticipated future regulatory drivers and mandates.

There are several types of sites where UXO contamination is an issue. These include Closed, Transferred, and Transferring (CTT) ranges, such as FUDS and BRAC sites, as well as sites on active and inactive ranges that are not scheduled for closure. Where sites are designated for civilian reuse, it is important that the UXO be removed to the extent possible and that proper safeguards be established where there is any possibility that live ordnance might still be in place. It is also important that a permanent record be maintained to document all measurements that are made to support clearance activities. Advanced technology, such as the airborne system, is expected to contribute to the performance of these activities in terms of effectiveness as well as cost.

With regard to the technology, the only regulatory agency involved in the implementation of this technology is the FAA. Because the boom mounting structure is bolted directly to the hard points of the aircraft, this installation becomes a modification to the airframe that requires FAA approval. These approvals were obtained in the form of an STC. This certificate was obtained by the aeronautics engineer at the time of manufacture and permits the installation of this equipment in any standard Bell B206L Long Ranger aircraft.

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7.0 REFERENCES

1. Bell, D. T., W. E. Doll, T. J. Gamey, and D. S. Millhouse. July 2002. Cost and Performance Report for the 1999 ESTCP Project Entitled “Evaluation of Footprint Reduction Methodology at the Cuny Table in the Former Badlands Bombing Range.”

2. Doll, W. E., T. J. Gamey, D. T. Bell, and D.S. Millhouse. July 2000. Evaluation of Footprint Reduction Methodology at the Cuny Table in the Former Badlands Bombing Range. Final Project Report/

3. McDonald, J. R., H. H. Nelson, R. Robertson, and R. A. Jeffries. September 1999. MTADS Unexploded Ordnance Operations at the Badlands Bombing Range. Final Project Report.

4. Bell, D. T., W. E. Doll, and D. S. Millhouse. July 1999. Remote Sensing Project at the Cuny Table Former Badlands Bombing Range. Proposal to the Environmental Security Technology Certification Program.

5. Andrews, A. M., E. Rosen, and I. Chappell. December 2001. Institute for Defense Analyses’ Review of Unexploded Ordnance Detection Demonstrations at the Badlands Bombing Range - NRL Multisensor Towed Array Detection System (MTADS) and ORNL High-Sense Helicopter Mounted Magnetic Mapping System (HM3). IDA Document Number D-2615.

6. Bell, D. T., W. E. Doll, and T. J. Gamey. August 2000. Airborne Geophysical Survey of Selected Department of Defense Sites in the Continental United States for the U. S. Army Engineering and Support Center, Huntsville in Support of the Environmental Security Technology Certification Program (ESTCP). White Paper.

7. Beard, L. P., W. E. Doll, T. J. Gamey, and D. T. Bell. 2004. Final Report on 2002 Airborne Geophysical Survey at Pueblo of Laguna Bombing Targets, New Mexico: ESTCP Final Report, April 2004.

8. Beard, L. P., D. A. Wolf, B. Spurgeon, T. J. Gamey, and W. E. Doll. 2003. Rapid screening of large area magnetic data for unexploded ordnance: Expanded abstract in Proceedings of 2003 SAGEEP Symposium, San Antonio.

9. Doll, W. E., P. Hamlett, J. Smyre, D. Bell, J. E. Nyquist, T. J. Gamey, and J. S. Holladay. 1999. A field evaluation of airborne techniques for detection of unexploded ordnance. Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, 1999, p. 773-782.

10. Doll, W. E., T. J. Gamey, and J. S. Holladay. 2001. Current Research into Airborne UXO detection. Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems. Denver, Colorado. Available on CD-ROM, 10 pp.

11. Gamey, T J., W. E. Doll, D. T. Bell, and J. S. Holladay. 2001. Current research into airborne UXO detection – Electromagnetics, UXO Forum, New Orleans, April 2001.

12. Gamey, T. J., W. E. Doll, A. Duffy, and D. S. Millhouse. 2000. Evaluation of improved airborne techniques for detection of UXO. Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, p. 57-66.

13. McDonald, J. R. and H. H. Nelson. 1999. MTADS Live Site Demonstration at Pueblo of Isleta, New Mexico, Report No. NRL/PU/6110-00-398, August 1998.

14. Nelson, H.H. and J.R. McDonald. 1999. Target shape classification using the MTADS. UXO/Countermine Forum 1999 Proceedings, Alexandria, Virginia, on CD-ROM.

15. Nelson, H.H., D. Wright, T. Furuya, J.R. McDonald, N. Khadr, and D.A. Steinhurst, 2004, MTADS Airborne and Vehicular Survey of Target S1 at Isleta Pueblo, Albuquerque, New Mexico, 17 February-2 March 2003: Naval Research Labs Report NRL/MR/6110—04-8764, 46 pp.

16. ORNL, 2005, 2002 Airborne Geophysical Survey at Aberdeen Proving Ground, Maryland, Final Report. ESTCP Projects 200037 and 37.

17. ORNL, 2005, Final Report on 2002 Airborne Geophysical Survey at Badlands Bombing Range, South Dakota. ESTCP Projects 200037 and 37.

18. ORNL, 2005, Final Report on 2002 Airborne Geophysical Survey at Pueblo of Isleta Bombing Targets, New Mexico. ESTCP Projects 200037 and 37.

19. ORNL, 2005, Final Report on 2002 Airborne Geophysical Survey at Pueblo of Laguna Bombing Targets, New Mexico. ESTCP Projects 200037 and 37.

20. ORNL, 2005, Final Report on 2003 Airborne Geophysical Survey at Pueblo of Isleta Bombing Targets, New Mexico. ESTCP Projects 200037 and 37.

21. Van, G. P., G. Calvert, L. P. Beard, T. J. Gamey, and A. M. Emond. 2004. Validation of Helicopter-Based Magnetic Survey at the Former Badlands Bombing Range. Expanded abstract in Proceedings of the Sixth Monterey Demining Symposium (MINWARA), Monterey, California, May 09-13, 2004.

APPENDIX A

POINTS OF CONTACT

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